CENTRAL MONTANA RAINSTORMS AND FLOODS JUNE 6–15, 1967

R. A. DIGHTMAN
Weather Bureau Airport Station, ESSA, Helena, Mont.

ABSTRACT

The meteorological features associated with the greatest flood of record (June 6–15, 1967) in the Central Musselshell River Valley of Montana are examined and the flooding and rainfall distribution are described and compared with other Eastern Montana flood-producing storms. Applications of RADAR to forecasting this flood are discussed. In some parts of the Musselshell drainage the rainfall intensity exceeded that of a 100-yr. probable maximum 2-day storm.

1. INTRODUCTION

Exceptionally heavy rains falling during a period of considerable mountain snowmelt flooded several Central Montana valleys during the first half of June 1967. Hardest hit were the Musselshell River above Melstone and several Yellowstone tributaries rising near the Wyoming border. Damage was of the order of several million dollars, and surface transportation was disrupted for about 10 days. The purposes of this report are to document in one place the extent of the flooding and some of its results, to review the synoptic history of the storm mechanisms involved, to comment upon the use of RADAR in this and future similar situations, to describe some characteristics of precipitation in the wetter areas, and to supply a condensed historical comparison with a few of Montana's past flood-producing rainstorms.

Several discharges measured by the U.S. Geological Survey were the highest of record. There were two flood periods—the first confined largely to the Musselshell drainage above Melstone during the June 6–8 period, the second covering many southern Yellowstone tributaries, as well as the same Musselshell area, on June 13–15. Besides being the most serious flood on record between Harlowton and Roundup on the Musselshell, this second flood, peaking only about 8 days after the first in roughly the same sections, has to be classed as a very unusual circumstance because the Musselshell is not a flood-prone river. The peak at Roundup, 12.45 ft. on June 18, exceeded the stage record set a week earlier on June 8, which in turn was the highest stage in the 20 yr. of record (11.0 ft. on June 18, 1948). See hydrographs in figure 1.

2. FLOODING AND DAMAGE

On the morning of June 7, 1967, it became apparent to forecasters at the Helena River District Office of the Weather Bureau that an extremely heavy rainstorm was occurring in the Central Musselshell Valley, and flooding was already in progress near Lavina and in parts of Flatwillow Creek north of Roundup (see figure 2 for map of area). The Montana Water Resources Board reported inflow into Petrolia Reservoir at record levels, and the Montana Highway Department reported water running across U.S. Highway 12 in several places. Flood warnings were issued promptly for downstream areas; and as it developed, flood forecasts were required for the next 12 days. Damage was extensive, and probably totaled several million dollars. The Mayor of Roundup estimated over $2.5 million in losses in that area—much of the south part of the city was under water for nearly 2 weeks. Railroads suffered traffic interruptions and washouts. Much river-bottom farmland was not usable for most of the 1967 growing season.

Following the storm of June 6–7, moderate showers continued for several days, and on June 13 a second heavy rainfall period started. The Musselshell River had remained very high, and the later rain period, although not as heavy as that of a week earlier, caused the river to reach even higher stages than the record-setting levels observed June 7–9. The June 13–15 rain period also affected the southern Yellowstone tributaries downstream from Big Timber to the Big Horn River. Little further damage was caused in the Musselshell River by the later flooding, but some southern tributaries of the Yellowstone, such as the Stillwater River, Bridger Creek near Greycliff, and several creeks above Cooney Reservoir, exceeded previous peak discharge records by a large margin. On June 14 U.S. Highway 87 was washed out, Upper and Lower Deer Creeks took out a section of Northern Pacific Railway main line, and of primary Highway U.S. 10. The Yellowstone River and its main tributaries experienced general but mostly minor flooding. Most of the damage (probably $1 to $2 million) appears to have occurred in tributaries flowing northward from the Absaroka Mountains.

In table 1 are data, provided by the U.S. Geological Survey, showing peak discharges, etc., available for the

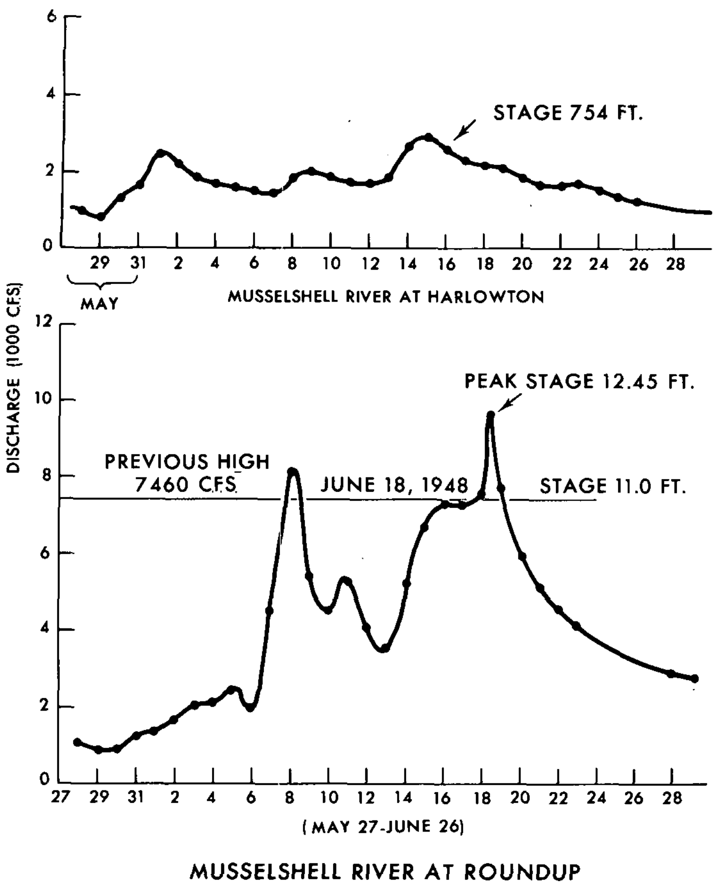


FIGURE 1.—Hydrographs for flood period, Harlowton and Roundup on Musselshell River.

general flood area. Indirect determinations of peaks on some additional streams were attempted, but without much success. On Pike Creek, tributary to Flatwillow Creek north of Roundup, a discharge of between 20,000 [1] and 25,000 c.f.s. was estimated, but there was good evidence that this peak came from only a small part of the creek's total (about 100 sq. mi.) drainage area, from a very intense short duration burst of rain, probably covering about 30 to 40 sq. mi. Provisionally, this would estimate a peak runoff for the smaller area of 666 to 833 [1] c.f.s. per sq. mi.

3. METEOROLOGICAL ANALYSIS

Experience has shown that heavy precipitation over Montana is usually linked to a more or less stationary 500-mb. trough or Low center near the 120th meridian. With the trough in this location, the 500-mb. ridge is usually established in the Gulf of Alaska between the 135th and 145th meridians. Such a pressure pattern persisted during a major portion of the spring months of March, April, and May 1967, and resulted in numerous storm periods. Great Falls reported precipitation on 30 days out of the 3 mo., with a total of 8.02 in. Helena also had 30 days of precipitation, with a total of 5.95 in.; and Billings reported 31 days with a total of 5.08 in. Precipitation at these three stations was about 70 percent above normal.

Snow surveys by the Soil Conservation Service and U.S. Geological Survey confirmed the existence of a heavier than normal snowpack in the higher mountains at the end of April and May. Prior to the middle of May, temperatures between the 5,000- and 10,000-ft. elevations were too low for sustained snowmelt. This was indicated by upper air soundings taken at Great Falls, and daily maximum and minimum temperatures reported at the valley stations of Livingston and Lewistown. Temperatures during the last 2 weeks of May and the first part of June were intermittently favorable for high elevation snowmelt, with peak warm periods reached on May 17, 21–23, 27–28, and June 2–3. It may be noted here that flooding of any severity east of the Continental Divide in Montana rarely occurs from snowmelt alone—substantial rains, such as occurred in this case, are usually required. There were no snow surveys following the flood period, but the hydrographs of figure 1 will help place snowmelt contributions in perspective as rainfall upstream from Harlowton was not particularly heavy during the storm periods downstream between Harlowton and Roundup.

Initial June precipitation of significance came the day after the June 2–3 warm period, with both Great Falls and Lewistown reporting close to ½ in. The first major rainfall period followed on June 5–7, with amounts in some areas totaling up to 7 in. During this time, there were frequent thundershowers over southeastern Montana, interspersed with longer periods of steady rain at most reporting stations located on the eastern slopes of the Rockies.

TABLE 1.—*U.S.G.S. peak measurements, general flood area. (All discharge figures listed are provisional and subject to adjustment.)*

Stream	Peak discharge (c.f.s.)	Date	Drainage area above gage (sq. mi.)	Runoff peak (c.f.s. per sq. mi.)
Musselshell Drainage				
S. Fork Musselshell above Martinsdale	1,180	6/8/67	287	4.1
N. Fork Musselshell above Martinsdale	103	6/12/67	233	0.4
Musselshell at Harlowton	2,880	6/15/67	1,125	2.6
American Fork below Lebo Cr. near Harlowton	1,560	6/14/67	166	9.4
Musselshell near Ryegate	7,000	6/15/67	1,982	3.5
Big Coulee near Lavina	2,470	6/18/67	232	10.6
Musselshell near Roundup	9,610	6/18/67	4,023	2.4
Musselshell at Musselshell	9,800	6/19/67	4,568	2.1
Musselshell at Mosby	11,400	6/18/67	7,846	1.4
Yellowstone Drainage				
Bighorn near St. Xavier	24,200	6/7/67	19,667	1.2
Stillwater near Absarokee	12,000	6/15/67	975	12.3
Red Lodge Cr. above Cooney Res.	2,260	6/15/67	143	15.8
Willow Cr. near Boyd	1,720	6/15/67	53.3	32.3
Bridger Cr. near Greycliff	2,680	6/14/67	61.5	43.5

[1] Preliminary estimate, subject to revision.

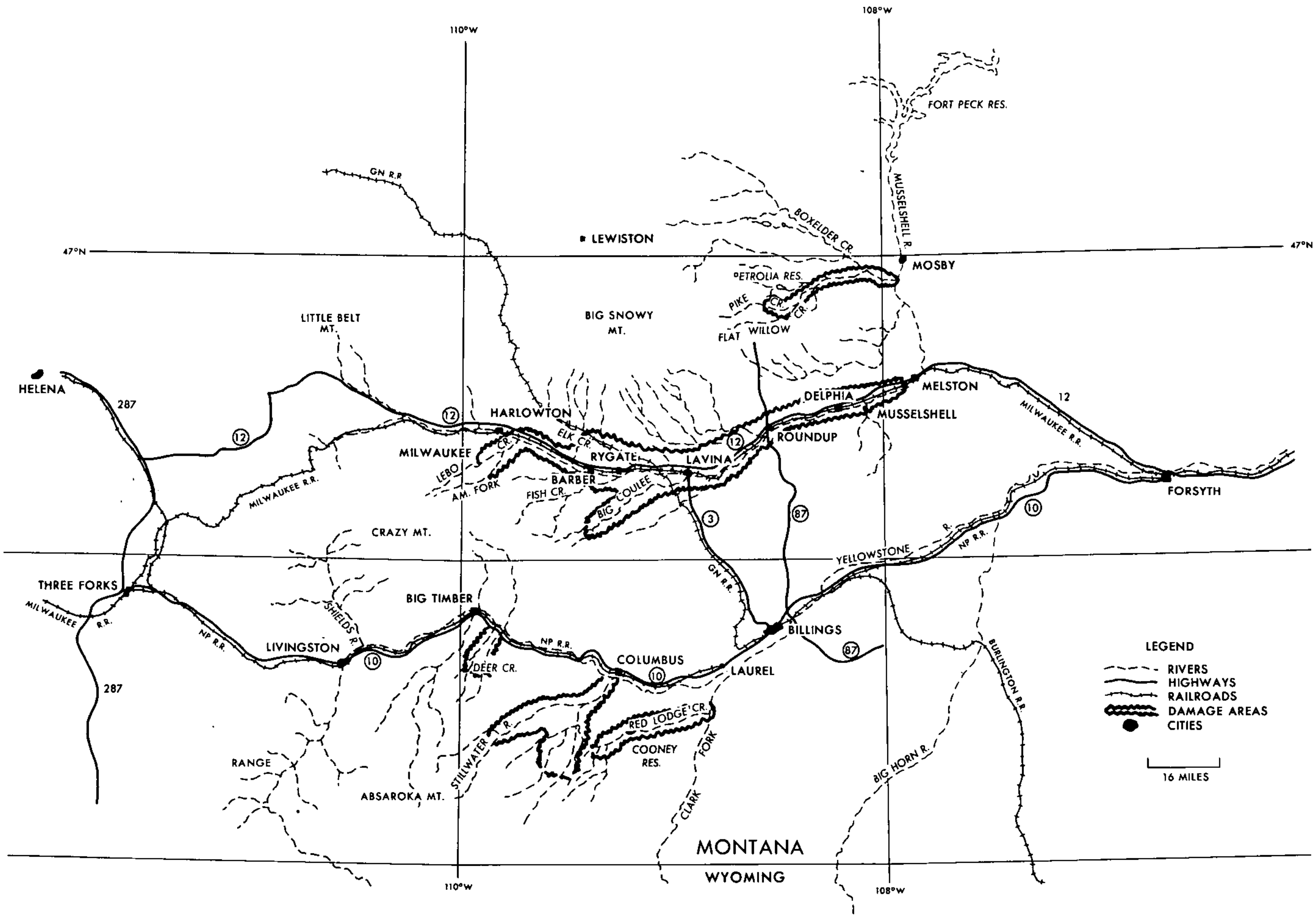


FIGURE 2.—Musselshell and portion of Yellowstone drainage.

Surface weather chart developments for the June 5–7 period are best discussed in relation to the higher level 700-mb. and 500-mb. charts. Figure 3 for these respective levels shows the progressive northeastward movement of the low pressure systems from a point off the coast of southern California on the morning of June 4, across California, Nevada, Idaho, and finally Montana on the 6th and 7th during the period of heaviest precipitation. The paths traced by the Low centers at 700- and 500-mb. were remarkably similar except that a 500-mb. secondary trough appeared over central Washington on the evening of June 6 and exhibited little movement for approximately 36 hr.

Although there is some question concerning the continuity, intermediate radiosonde observations suggest that the original 500-mb. closed Low remained dominant and that the secondary trough over Washington merged into the closed Low as it moved across Montana and thence eastward into North Dakota on June 8.

The continuity of fronts and pressure patterns appearing on the surface charts during the June 5–8 rain period was somewhat obscure. The most significant characteristic was the maintenance of a low level circulation favoring the transport of moisture northward from the Gulf of Mexico and across the western plains, reaching the Big Horn Mountains of northern Wyoming and southern Montana by the morning of June 5. This source of moisture remained available for the next 2 days while heavy rain fell over much of southeastern Montana.

One feature which appeared on most of the surface charts was a stationary front across central Wyoming which maintained separation between the family of Lows to the south and the higher pressure over Montana and northward (fig. 4). The Lows were associated with the main upper trough which was then moving northeastward from California. One such low cell moved across Wyoming into the Dakotas on June 5, but without much effect except for a temporary cutoff of moisture injection from the southeast.

The more significant development began on the 6th, with a rash of thundershowers over southern Montana and Wyoming. Radar reports between 0935 MST and 1335 MST clearly indicated a sudden increase in convective activity within a 150-mi. radius of Yellowstone Park that persisted through the afternoon. About this time, a weak cold front moving southward from Canada had reached the southern border of Montana, but then it became more diffuse as pressures began falling behind it. A weak surface Low appeared over northeastern Wyoming by evening and moved northward during the night to a position about 100 mi. southeast of Lewistown, Mont.,

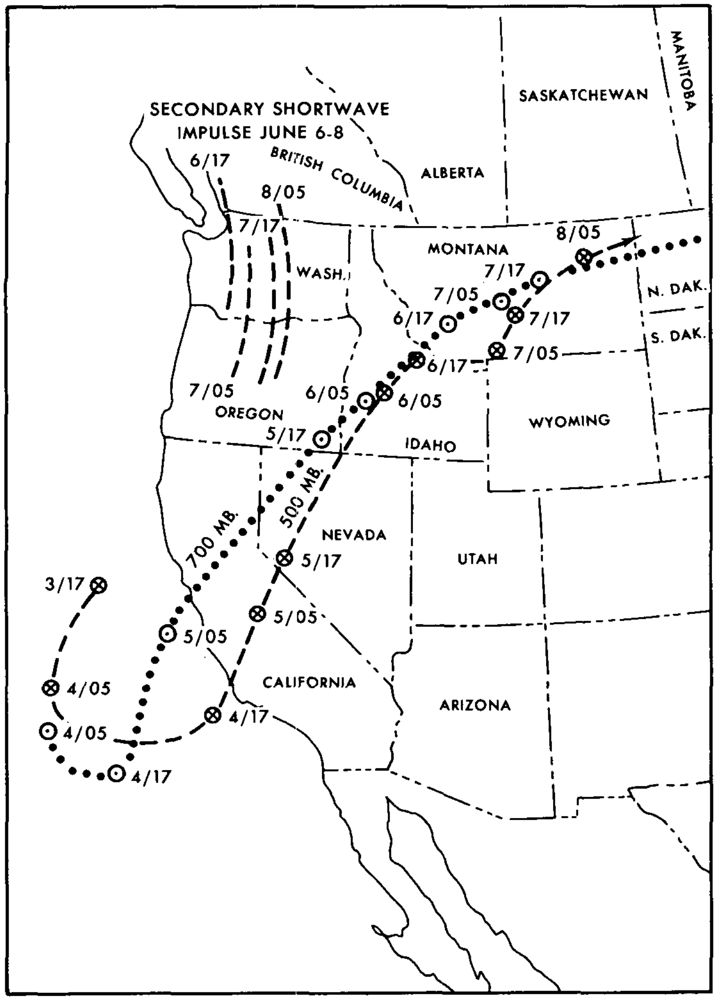


Figure 3.—Paths of closed 700-mb. Low (10,000 ft. m.s.l.) and 500-mb. Low (18,000 ft. m.s.l.) at 12-hr. intervals, June 3–8, 1967 (times are MST).

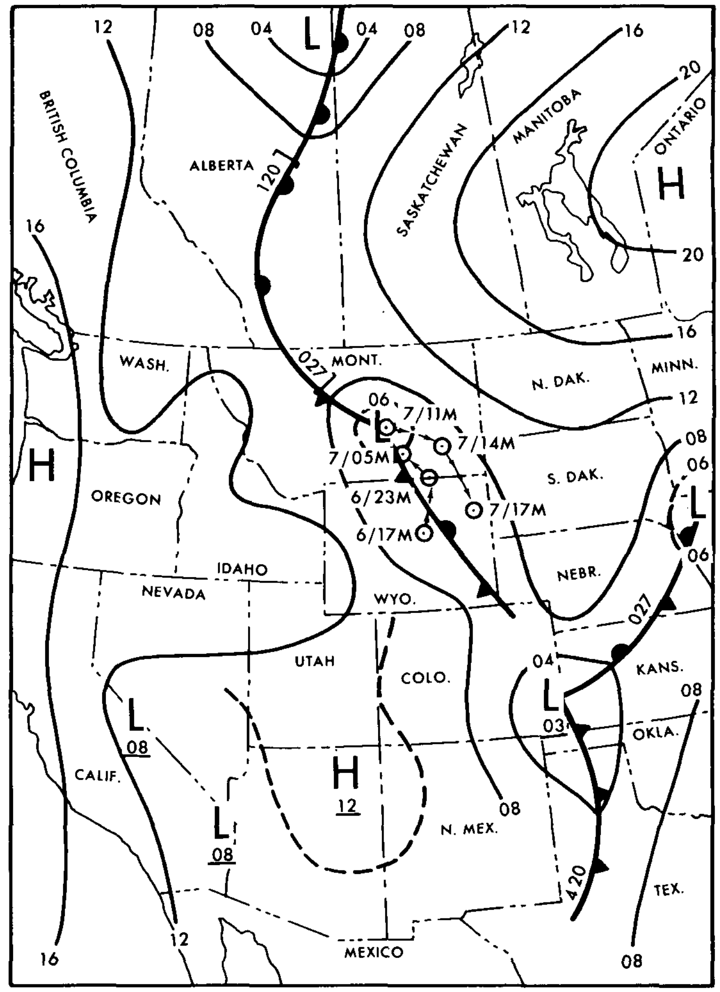


Figure 4.—Surface weather chart, 1100 MST, June 7, 1967.

by 1100 MST on the 7th (fig. 4). With continuing heavy rainfall and embedded thunderstorms, the Low center reversed direction about noon on the 7th and began moving rapidly toward the southeast so that the track of center positions formed a loop, as shown in figure 5. Reference to figure 3 shows that the looping took place at about the same time the 700-mb. and 500-mb. closed Lows moved to positions which were almost directly above the surface Low position.

Heaviest rainfall evidently occurred during the period when the surface Low made the loop in southeastern Montana, and at a time when the slope of the closed circulation became more nearly vertical. It is also evident that the heavy rain cannot be correlated with geographic features which would emphasize orographic lift. For example, a 7-in. rainfall maximum was reported at Lavina, located in the bottom of the Musselshell River Valley. Hence, the heavy rain apparently resulted primarily from dynamic processes that occurred in an air mass which was continuously supplied with abundant moisture from the southeast. The Rapid City upper air sounding indicated the unstable nature of this air mass which suggests that extensive thunderstorm activity could be triggered by the arrival of the closed Low and subsequent cooling aloft.

Following the heavy rainfall over the watersheds of the Musselshell and Yellowstone Rivers June 6–7, relatively light showers fell on the 8th and 9th, while temperatures at the 5,000-ft. level remained between 45 and 60°F. The next important storm period in Montana began early on the morning of June 10, when a well-marked cold front from Canada moved southward to the northern border of Wyoming soon after 1800 MST. The ensuing surface pressure pattern remained relatively unchanged during the 5-day period through June 14 with higher pressure remaining over Montana and Alberta. This High was separated from the numerous Low centers to the southwest through southeast by a stationary front whose mean position extended from northern Idaho southeastward across central Wyoming and then northeastward into North Dakota. This front became more diffuse on the 12th, but later regained its identity when higher pressure surged from the north. Figure 6 shows the surface chart for 1100 MST, June 13. Organized centers of action throughout this period were hard to detect, and their movement difficult to follow. One ill-defined center over the Texas Panhandle on June 11 could be tracked northward as far as North Dakota by the evening

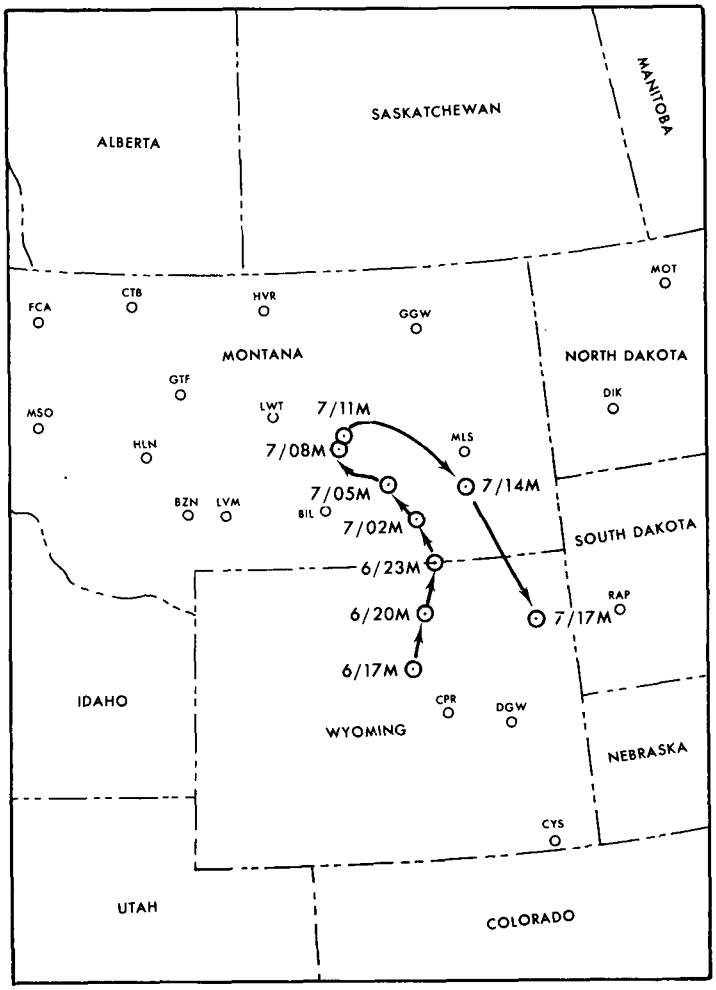


FIGURE 5.—Path of surface low pressure center at 3-hr. intervals from 1700 MST, June 6 to 1700 MST, June 7, 1967.

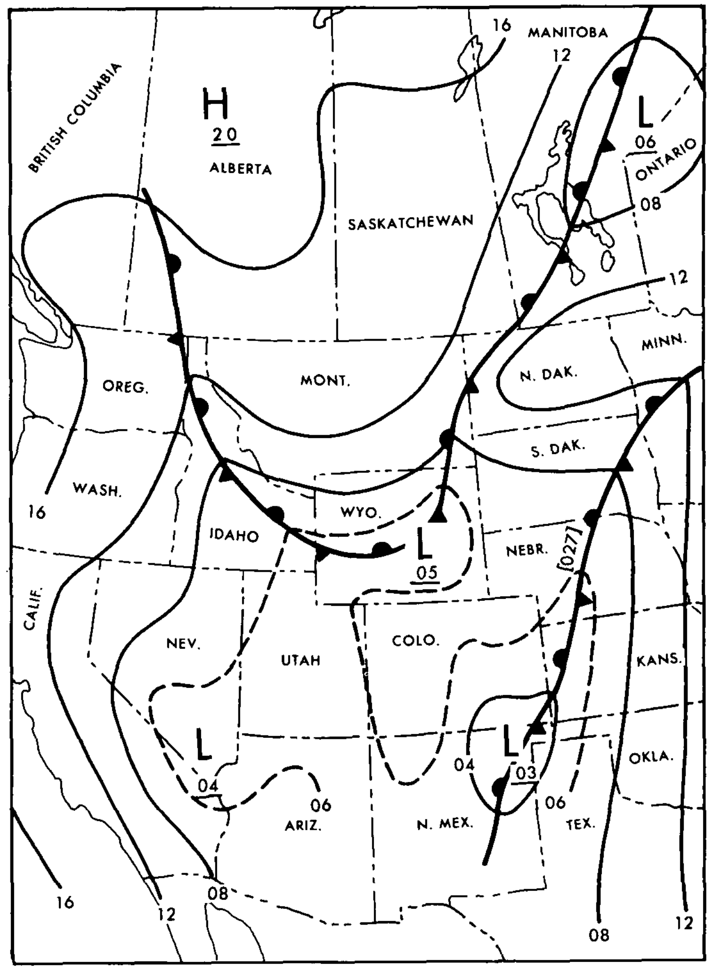


FIGURE 6.—Surface weather chart, 1100 MST, June 13, 1967.

of June 12. This movement served to increase the already adequate flow of moisture from the Gulf of Mexico northward into southeastern Montana.

The upper air pattern for the June 10–14 rain period was more complex than the one for the June 5–7 rain. Figure 7 shows that a 700-mb. closed center remained stationary near Edmonton, Alberta, until the evening of the 11th and then began a rapid southerly movement which carried it through eastern Washington, eastern Oregon, and into northern Nevada before recurving near Ely, Nev., at 0500 MST on the 13th. This figure also shows the position of 500-mb. Low centers for the period June 11–15. On the morning of the 11th, there was a Low center near Edmonton and another on the southwest coast of British Columbia. The latter moved southeastward to a point over northeastern Oregon by 0500 MST on the 13th. At that time a new Low center formed over southern Nevada while the center over Oregon filled. On June 13–15 both the 700-mb. and 500-mb. Lows followed a northeastward track across Utah into southern Wyoming, where they became open troughs.

The light rains of June 10–11 occurred while the upper closed centers were still to the northwest. The heavier rain beginning on the 12th was apparently associated with the rapid southward movement of the Low aloft and the weak surface surge of higher pressure from the north. Heavy rains on the 13th and 14th were associated with the upper Low moving northeastward into Wyoming.

Further explanation of this rain period may be obtained by reference to the mean 850-mb. chart constructed from 10 individual charts, June 10, 1700 MST through June 15, 0500 MST (fig. 8). This chart shows the mean center of the Low to be located over Colorado, favoring a continued flow of moisture northward from the Gulf of Mexico and thence westward into Montana. Most of the individual 850-mb. charts during this period showed southerly winds of 30 to 45 kt. over extensive areas in the Western Plains. This was also an area of high dew points, with an average of more than 10°C. When the moist air mass reached eastern Montana, it was subjected to both orographic lift and the gentle upglide over a dome of cooler air. It was, in fact, a sequence of weather events not unusual for this time of year.

The significant elements of similarity between the two peak rainfall periods were the locations of a stationary 500-mb. trough over northwestern United States, and the low level circulation which transported moisture into Montana from the southeast. These features are also found in nearly all other flood periods over Montana

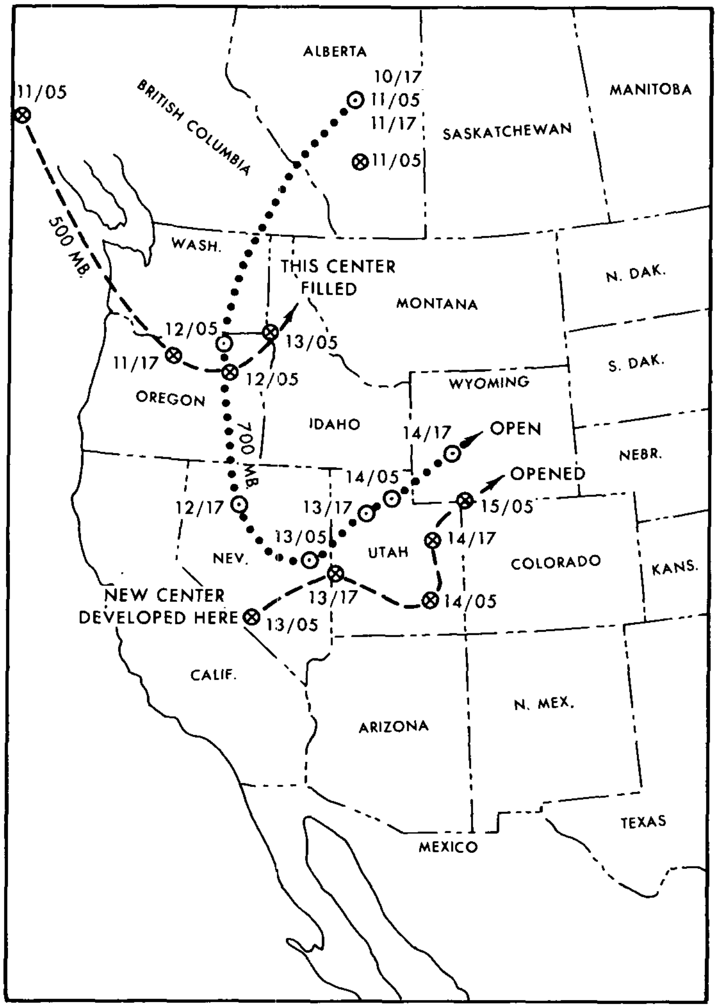


FIGURE 7.—Paths of closed 700-mb. Low and 500-mb. Low at 12-hr. intervals, June 11–15, 1967 (times are MST).

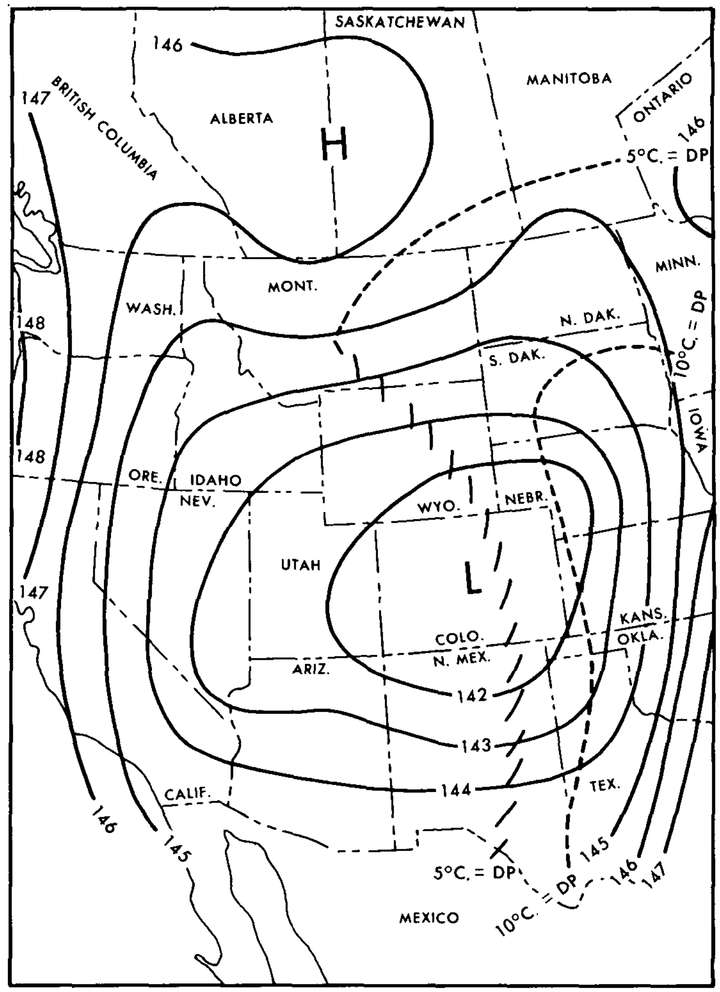


FIGURE 8.—Mean 850-mb. chart, 1700 MST, June 10 to 0500 MST, June 15, 1967, inclusive. (5°C. dew point isotherm broken along approximate ground elevation of 5,000 ft., m.s.l.)

east of the Continental Divide. The meteorological significance of the 500-mb. trough along the 120th meridian may be summed up as follows:

1) Smaller scale impulses and/or closed Lows moving northeastward out of this large-scale trough through Idaho into Montana or Wyoming are associated with sufficient cooling aloft to trigger extensive thunderstorm activity.

2) This pattern supports a surface High cell over Alberta and a family of surface Lows moving through Wyoming or Montana which combine to give upslope effects east of the Continental Divide favorable for general precipitation.

3) The induced low level circulation transports moisture from the Gulf of Mexico northward and thence westward into eastern Montana.

The two peak rainfall periods differed in some respects. The first period was potentially more serious because of the nearly vertical slope of the closed circulation and the threat of heavy thunderstorms. The second situation would have become even more serious for flooding if the Low aloft had remained closed and moved northeastward over Montana instead of opening up over Wyoming (fig. 7). From the flood aspect, however, it was at least as important because its rainfall came on top of streams already swollen by the rains of the preceding 10 days.

Both storm periods were accompanied by pressure patterns which occur from time to time during the May–June rainy season and have been associated with flood-producing storms of other years.

4. RADAR COVERAGE

This was the first significant Montana flood situation to be covered reasonably well by radar—the 1964 flood occurred during equipment outages of the only radar within range. During the 1967 floods, FAA Traffic Control radar located near Lovell, Wyo., and north of Ashton, Idaho, proved quite useful in several ways, and the higher cloud buildups were seen also from the ESSA Weather Bureau WSR-57 scanner atop Point Six Mountain near Missoula, Mont. The Lovell and Ashton Radars are used primarily for air traffic control but excellent cooperation between controllers and radar meteorologists produced

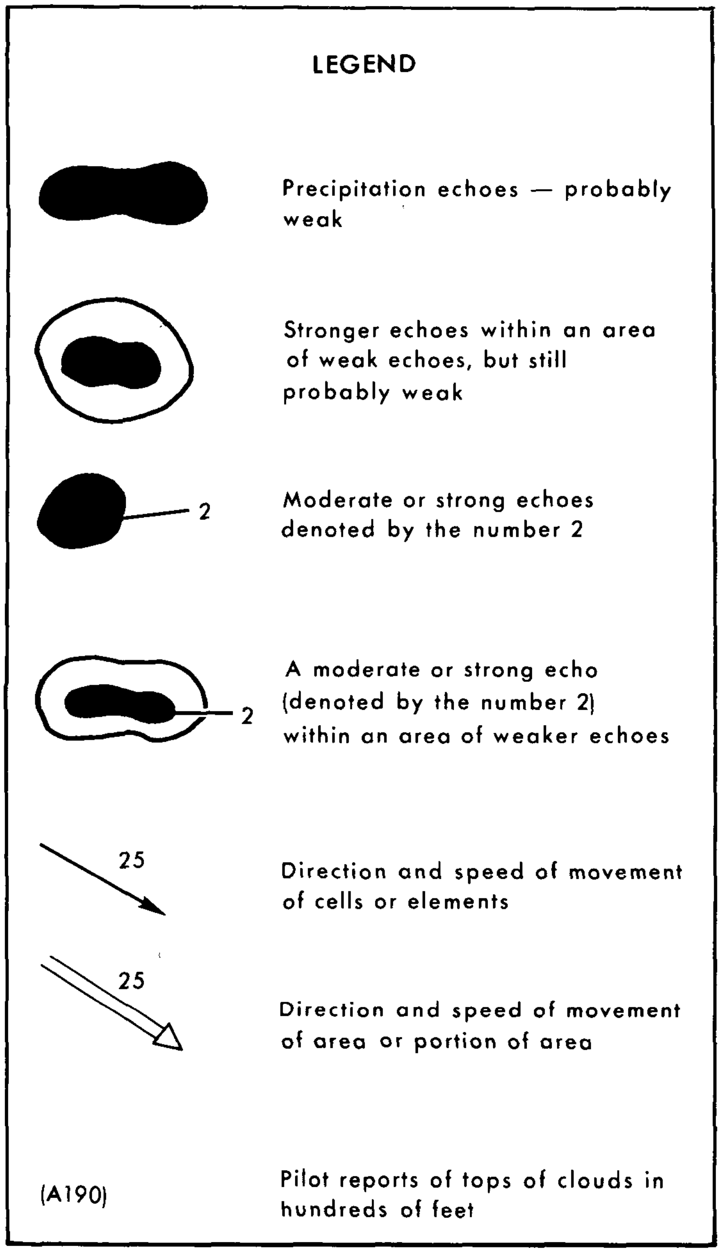


FIGURE 9.—Legend for radar charts, figures 10–16.

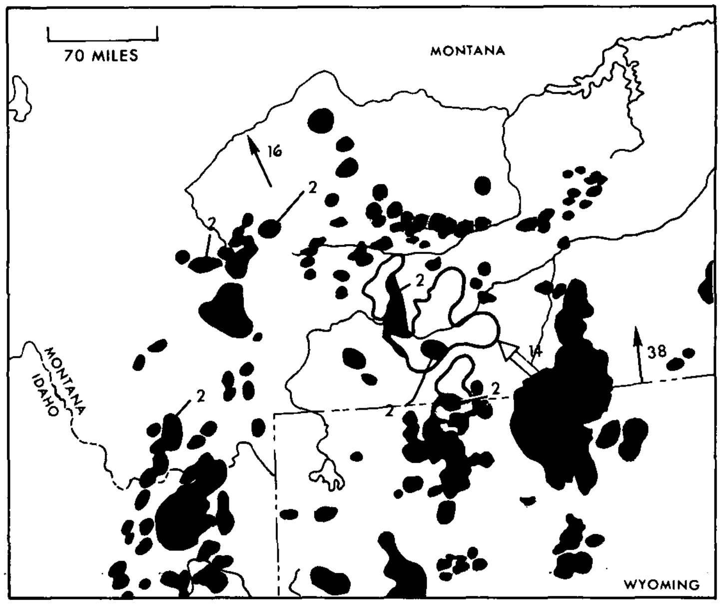


FIGURE 10.—Radar echo pattern, 1535 MST, June 6, 1967. Note density of echoes (some high intensity) south-central Montana.

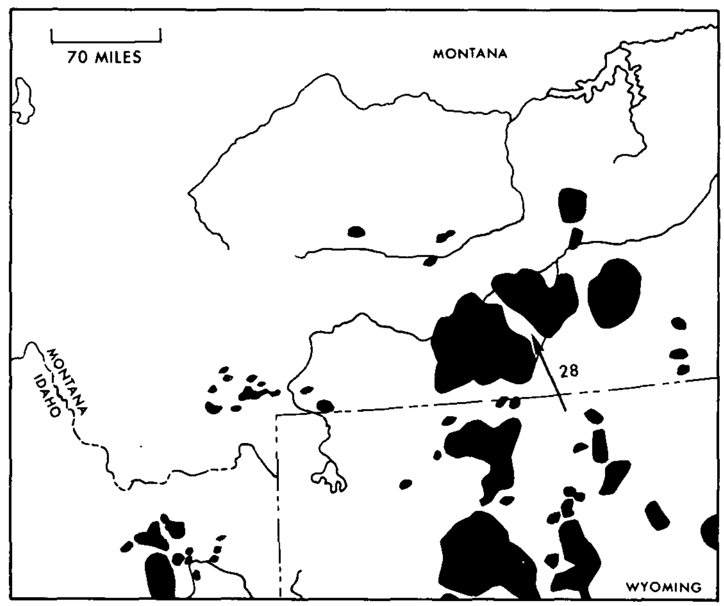


FIGURE 11.—Radar echo pattern, 1735 MST, June 6, 1967. Note large strong area headed toward middle Musselshell Valley.

valuable data during these storm periods. River District Offices at both Billings (Yellowstone River) and Helena (Musselshell River) received timely warnings from the Salt Lake City, Utah, Weather Bureau radar meteorologist, especially June 13–15.

Figure 9 shows the legend for the RADAR charts to follow (fig. 10–16). Figure 10 depicts the echo pattern in central Montana at 1535 MST, June 6, showing a number of small echoes of high intensity. By 1735 MST the echoes were well concentrated along the Yellowstone River upstream from Billings (fig. 11), and were advancing toward the central Musselshell drainage to the north-northwest at about 28 kt. There were no more charts on June 6, but it is significant that 1.26 in. of rain fell at Lavina (see fig. 17) between 9 and 10 p.m., some 60 to 80 mi. downwind from the echo center of figure 11.

By 0735 MST, June 7, a large echo was again located over the central part of the Musselshell Basin (fig. 12). This echo pattern did not start breaking up until about 1300 MST or 1400 MST, and should be considered in connection with the 1100 MST surface weather chart (fig. 4). Figure 13 shows the echo pattern at the time the major part of the storm began to weaken. Showery weather continued in the general area until the next maximum precipitation period started on June 13, with nearly all stations

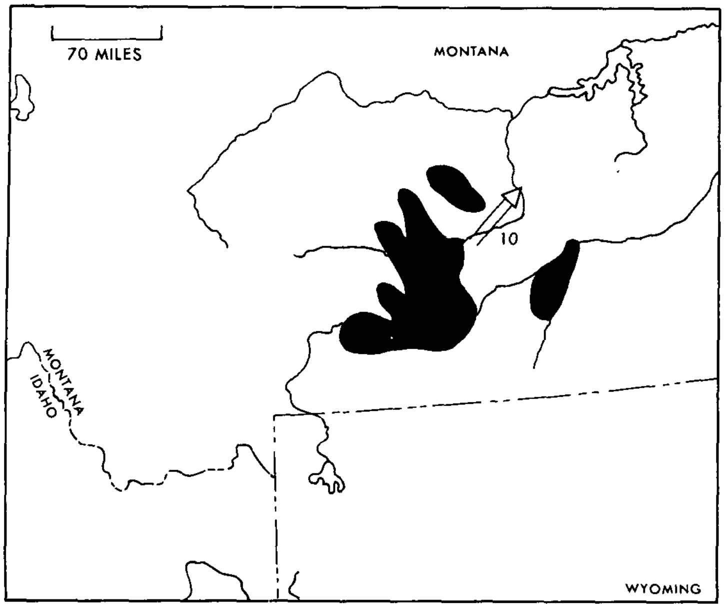


FIGURE 12.—Radar echo pattern, 0735 MST, June 7, 1967. Echo pattern may have persisted overnight—heaviest rains fell at Lavina during hours just after midnight.

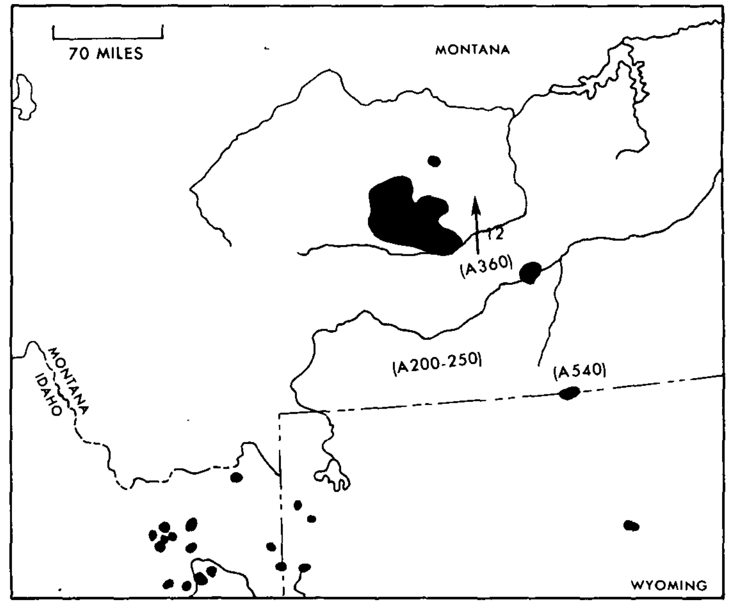


FIGURE 14.—Radar echo pattern 1135 MST, June 13, 1967. Echo pattern organized north of area struck by June 6–7 storm.

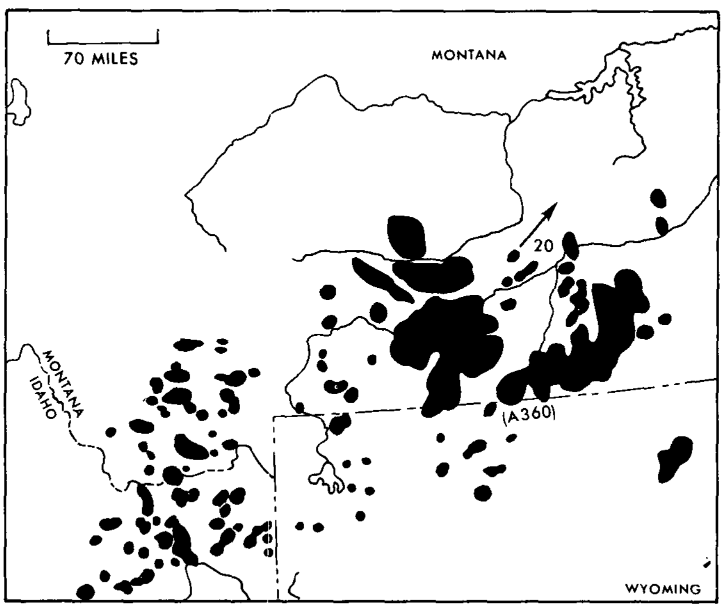


FIGURE 13.—Radar echo pattern, 1335 MST, June 7, 1967. Note apparent breaking up of solid echo area.

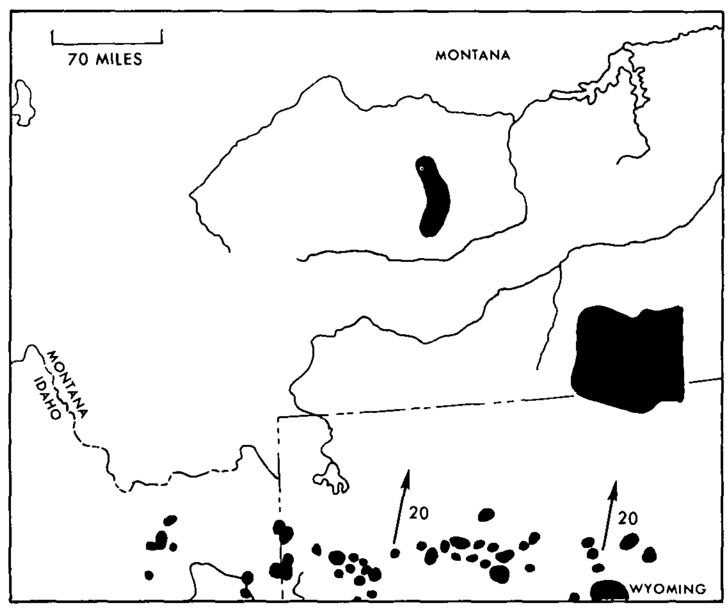


FIGURE 15.—Radar echo pattern, 1535 MST, June 13, 1967. At this time concern was for reflooding the same area of Musselshell as was covered a week earlier.

measuring at least small amounts of rainfall (3), and with large amounts at many places from June 12–14. The Musselshell area was still flooding as a result of downpours a week earlier and the continuous showery weather thereafter.

At about 1400 MST, June 13, both Helena and Billings River District Offices were alerted by the Salt Lake City radar staff, and this alert was the basis upon which telephone calls were made to several cooperative observers in the affected areas—the calls confirmed that heavy rains were indeed occurring for the second time in a week. New flood warnings were issued, and peak discharges in many tributaries of both Musselshell and southern Yellowstone drainage again reached or exceeded records set only a week earlier.

Figure 14 shows the echo pattern at 1135 MST, June 13. Echoes of this type observed at 0610 MST moved northward at 10 to 15 kt. These echoes did not disappear from the scopes until after the 1535 MST chart (fig. 15). By this time they were probably above the north Musselshell drainage. At 0935 MST, June 14 (fig. 16), a large well-organized echo appeared over Yellowstone Park. During

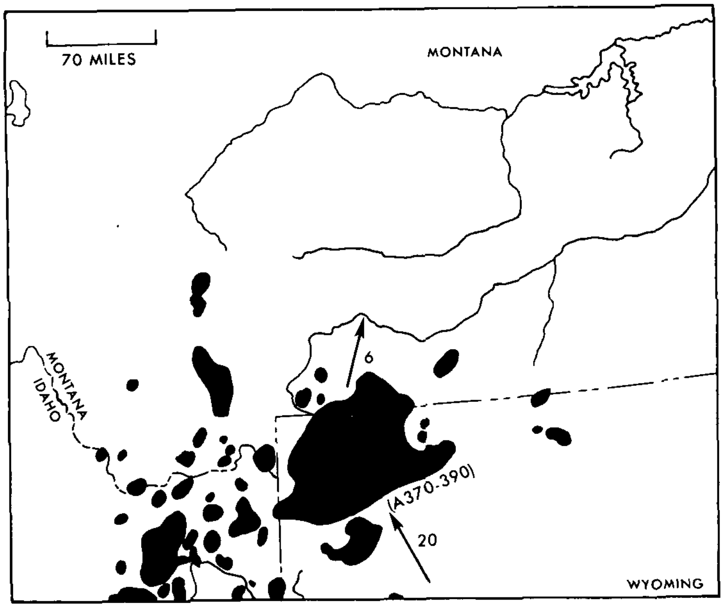


FIGURE 16.—Radar echo pattern, 0935 MST, June 14, 1967. Musselshell rains largely over but note solid area on Yellowstone south drainage. This echo area extended northward slightly, then gradually broke up.

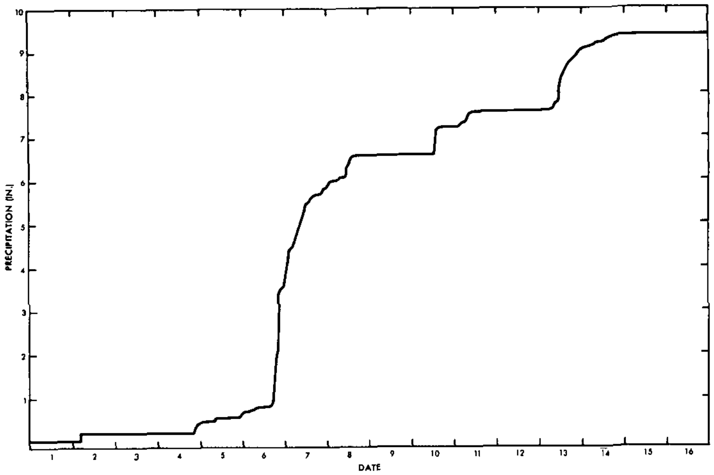


FIGURE 17.—Mass rainfall distribution, Lavina, Mont., June 1–16, 1967.

the following 6 hr. this echo changed little, and appears to have been associated with heavy rains that caused highway and railroad washouts on southern Yellowstone tributaries 30 to 60 mi. downstream from Livingston.

5. RAINFALL DISTRIBUTION

The approximate rainfall patterns for the two storm periods (June 6–7 and 13–15) and for the 10-day period June 6–15 are shown in figures 18 and 19. Isohyetal lines have been smoothed somewhat, but depicted water volume indications should be reasonably close. After the first storm, an effort was made to conduct a "bucket survey" over the affected area, but the survey was only partly successful because it overlapped the second storm period. Washouts, from primary highways to seldom-used country roads, were insurmountable in many instances. Nevertheless, a number of supplementary measurements were obtained, and the full listing appears in *Climatological Data, Montana, December 1967.* All measurements collected, official and other, were used in developing figures 18 and 19. Also used were amounts from regular stations as published in [3].

The most noteworthy features of the rainfall patterns include: 1) the large extent of heavy rain June 6–7, roughly northeast-southwest, and almost superimposed on the Musselshell main stem; 2) the smaller but also intense heavy centers near and west of Ekalaka in northern Carter and Powder River Counties in southeastern Montana; 3) the evidence provided by radar and total rainfall amounts suggesting that rainfall maxima were not related to topographic features except in a general way. As pointed out in section 3, the heaviest rainfall amounts probably resulted from dynamic processes in the air masses involved. The generally small upslope of only a few feet per mile toward the west probably increased rainfall totals only slightly.

Limitations due to the natural high rainfall variability in time and space, and the small but not negligible effects of nearby hills and mountains should be borne in mind when studying the isohyetal portrayal of this storm period. While total volume represented is thought to be within reason, it seems likely that local variability was higher than the smoothed charts indicate. U.S. Geological Survey measurements (table 1) also suggest a higher variability in point rainfall than the charts are capable of showing because of lack of density in the network measurement grid.

Hershfield [1] indicates a 24-hr. rainfall maximum of about 2.90 in. in the Lavina area with a return period of 25 yr., and about 3.25 in. for 50 yr. Miller [2] shows about 4.2 in. for a 100-yr. return period for a 2-day rainfall. It should be noted here, however, that there is no assurance that the maximum center was measured—there could have been (and most likely was) more than 5.30 in. in 2 days at some nearby points, considering the dynamic characteristics of the storms. However, the storm of June 6–7 as a whole appears to have remained well within the probable maxima indicated in [1] and [2], with the possible exception of the small centers near Ekalaka westward, and in a portion of Pike Creek (Flatwillow Creek tributary) north of Roundup.

6. COMPARISONS WITH OTHER MONTANA STORMS

This is the first known attempt at a reasonably complete documentation of a major rainstorm over the Musselshell and Middle Yellowstone Valleys of Montana, and it seems appropriate to provide a rough comparison of storm totals for some selected earlier Montana flood-producing rains. Totals and durations for a few earlier cases are listed in table 2. Prior to the 1948 Marias flood, documentation is somewhat sketchy, but reports [4, 5, 6]

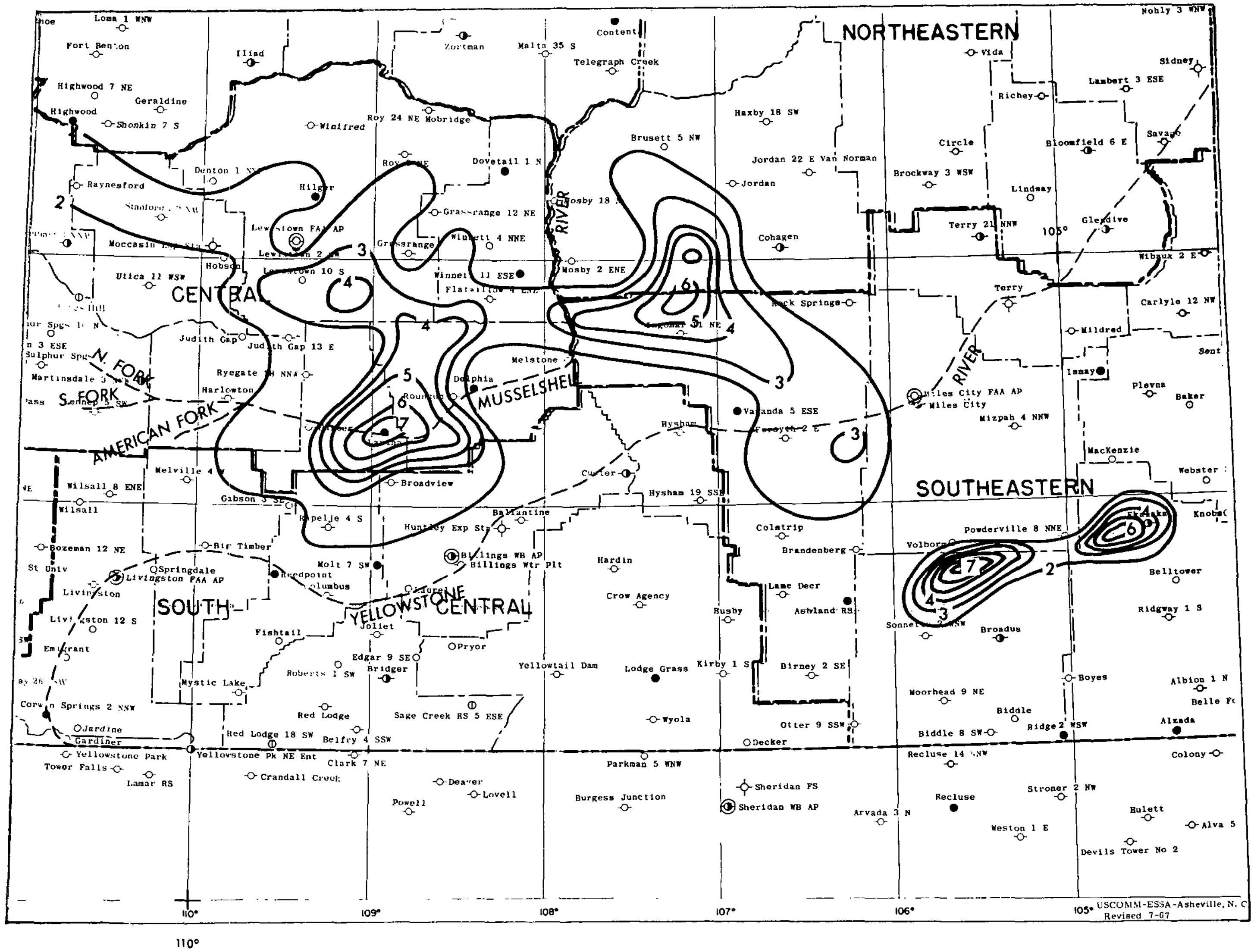


FIGURE 18.—Isohyetal chart, June 6–7, 1967. Rainfall was most intense during early morning hours June 7. Lines have been smoothed, but are based upon actual measurements.

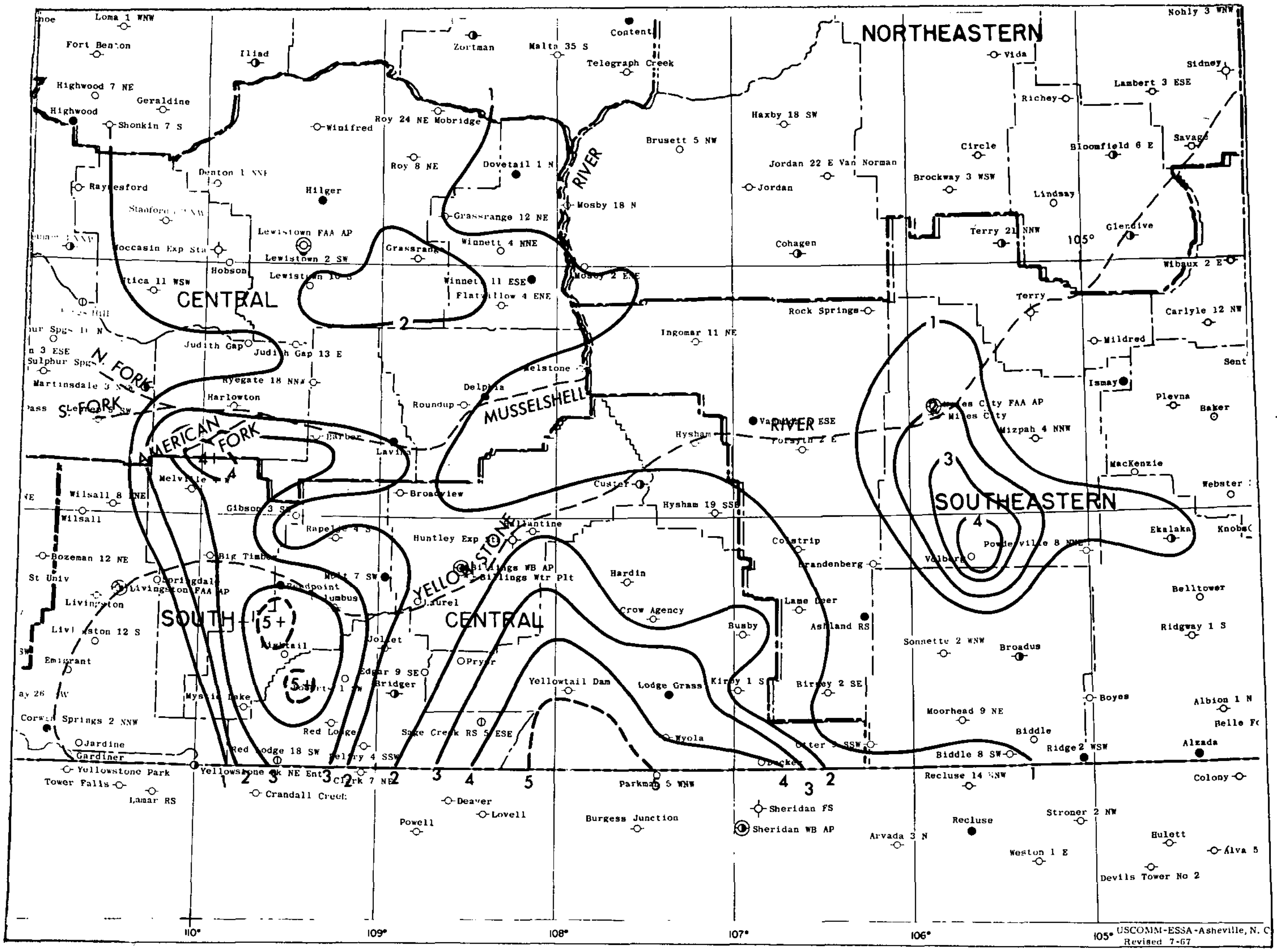
cover important floods and associated storms in some detail. There are now four important rain-induced flood situations for which contributing weather conditions have been rather fully described.

It is appropriate to comment upon differences as well as similarities. As noted in the meteorology discussion, the combination of atmospheric elements that develop flood-producing rainstorms in eastern Montana is much the same in each case[2]—except as to degree and location. Required are a moist air source (usually the Gulf of Mexico), a cold vortex aloft south to southwest of the heaviest storm area, and—in the most intense rainfall situations—low level upslope winds from an easterly quadrant. The intensity of the rainfall depends upon the degree of development of each element; it is only when all are fully developed that the heaviest storms occur, as in 1964. In spite of notable similarities between these storm types, each future storm will have its own characteristics in degree, location, etc., and will be a separate case. While it is exceedingly important to be aware of the general storm characteristics involved, each future storm will warrant individual study by meteorologists, hydrologists, and engineers.

[2] The floods of 1952 in the Milk River were an exception—snowpacks were primarily responsible when warm weather came at the end of March, following a long, cold, snow-accumulation period over the entire basin. This separate flood type is described in [7].

ACKNOWLEDGMENTS

The section on radar coverage is based upon material provided by DeVon B. Smith, Supervising Radar Meteorologist, Weather Bureau Airport Station, Salt Lake City, Utah. Section 3, Meteorological Analysis, was prepared by Meteorologists Warren B. Price, William A. Grimes, and Warren G. Harding, of the Great Falls Weather Bureau Forecast Center. Material on Yellowstone flooding was supplied by Norris E. Woerner, Meteorologist in Charge of the Billings Weather Bureau River District Office. The bucket survey was led by Gary M. Malchus, Montana Weather Bureau Field Aide; the Soil Conservation Service, U.S. Bureau of Reclamation, Corps of Engineers, and U.S. Geological Survey representatives also worked in the area. Basic work on isohyetal charts and precipitation tabulations was done by Hydrologist David A. Westnedge, Weather Bureau River District Office, Helena, Mont.



110°

FIGURE 19.—Isohyetal chart, June 13–15, 1967. Note centers southwest of Columbus, and on American Fork of the Musselshell. Dashed isolines indicate estimated centers.

TABLE 2.—*Totals and durations of earlier flood-producing rains in Montana*

Location and Date	Precipitation: Total (in.)	Precipitation: Duration (hr.)
Warrick, June 6-8, 1906	13.3	54
Evans, June 3-7, 1908	10.1	120
Springbrook, June 17-21, 1921	(a) 15.1	(a) 108
Dupuyer, June 16-17, 1948	9.1	36 [4]
Lloyd, May 23-June 4, 1953	11.8	13-day [5]
Browning, 20 mi. W., June 7-8, 1964	16.0	30 [6]
Lavina (near), June 6-7, 1967	7.0	48
TIS, R50E, Sec. 29, June 6-7, 1967	8.3	48

(a) 10.5 in./6 hr.

REFERENCES

1. D. M. Hershfield, "Rainfall Frequency Atlas of the United States for Durations From 30 Minutes to 24 Hours and Return Periods From 1 to 100 Years," *Technical Paper* No. 40, U.S. Weather Bureau, Washington, D.C.. May 1961, 115 pp. (see pp. 54–55).
2. J. F. Miller, "Two- to Ten-Day Precipitation for Return Period of 2 to 100 Years in the Contiguous United States," *Technica Paper* No. 49, U.S. Weather Bureau, Washington, D.C., 1964 29 pp.(see p. 11).
3. Environmental Data Service, ESSA, *Climatological Data, Montana*, Vol. 70, No. 6, June 1967, pp. 112–114.
4. R. A. Dightman, "Montana Marias Basin Rainstorm, June 16–17, 1948," *Monthly Weather Review*, Vol. 78, No. 1, Jan. 1950, pp. 6–12.
5. U.S. Geological Survey, "Floods of May–June 1953 in Missouri Basin in Montana," *Water Supply Paper* No. 1320-B, Washington, D.C., 1957, pp. 81–86.
6. U.S. Geological Survey, "Floods of June 1964 in Northwestern Montana," *Water Supply Paper* No. 1840-B, Washington, D.C., 1967, pp. 16–49.
7. U.S. Geological Survey, "Floods of April 1952 in the Missouri River Basin," *Water Supply Paper* No. 1260-B, Washington, D.C., 1955, pp. 49–302.

[*Received February 8, 1968; revised May 13, 1968*]

PICTURE OF THE MONTH

Convective Cloud Systems

FRANCES C. PARMENTER

National Environmental Satellite Center, ESSA, Washington, D.C.

Pictures currently receivable at frequent intervals from NASA's Applications Technology Satellites now give meteorologists a means for directly observing short-lived small-scale cloud features. These pictures are particularly useful for studying the growth and decay of convective cloud systems. Enlargements of sections of four ATS-III pictures (fig. 1–4), taken June 21, 1968, show changes in several mesoscale cloud systems.

The development of afternoon thunderstorms over Florida (P), Cuba (Q), Jamaica (R), and Haiti (S) is particularly striking. At 1246 EDT (fig. 1), these land areas are easily identified by the presence of fair weather cumulus and long cumuliform cloud lines. Within 2 hr. (fig. 2), a substantial increase in the size and vertical height of the clouds, especially over Cuba, can be seen. Surface reports at 1800 GMT (fig. 5), indicate that rain is already occurring in southeastern Cuba. By 1525 EDT (fig. 3), the individual cumulonimbus clouds have merged, resulting in the large bright clusters at P, Q, R, and S. The gray, fuzzy-appearing edges of these clusters indicate that cirrus plumes are starting to form. In figure 4, the cumulonimbus clusters are well established with long cirrus plumes extending to the north.

It is interesting to note that while thunderstorms are developing over Florida and Cuba, the active cells seen over the Bahama Islands, in figure 1, slowly dissipate during the day.

Another mesoscale cloud feature appears along the East Coast of the United States. Here, a thin line of cumuliform clouds develops between figures 1 and 2. This line marks the area of convergence associated with the sea breeze.

Changes in the cloud pattern associated with hurricane Brenda can also be seen. Brenda, which at 1800 GMT was located about 400 mi. due east of Jacksonville, Fla., appears in the upper right-hand corner of these pictures. It is interesting to note that within this 5-hr. period, the numerous curved cumulus cloud lines along the western and southern quadrants of the storm, in figure 1, become less pronounced and are spaced farther apart by figure 4, while the central cloud structure of the storm appears to become more organized.

Study of these and successive ATS photographs will provide meteorologists with a greater understanding of the development and dissipation of tropical cloud systems and depressions, easterly waves, and hurricanes.

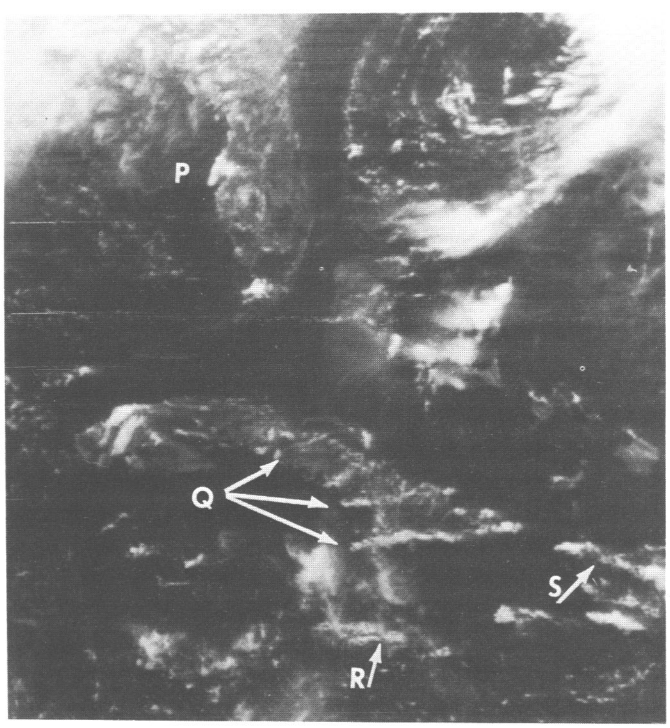


FIGURE 1.—ATS-III, June 21, 1968, 1646 GMT (1246 EDT).

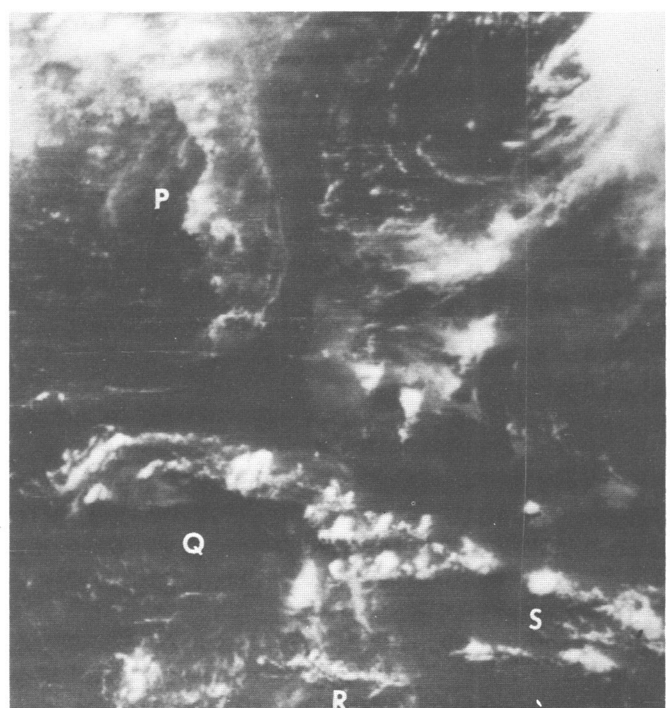


FIGURE 2.—ATS-III, June 21, 1968, 1819 GMT (1419 EDT).

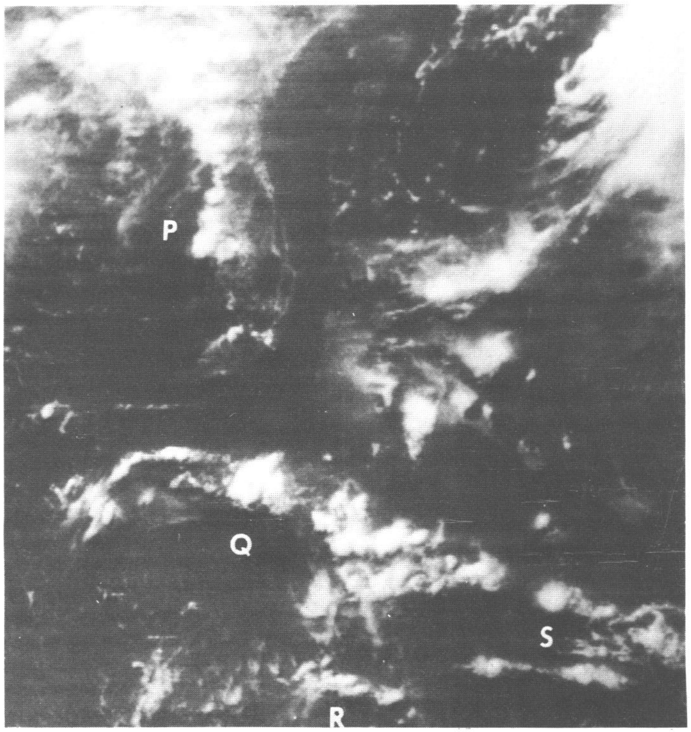


FIGURE 3.—ATS-III, June 21, 1968, 1913 GMT (1513 EDT).

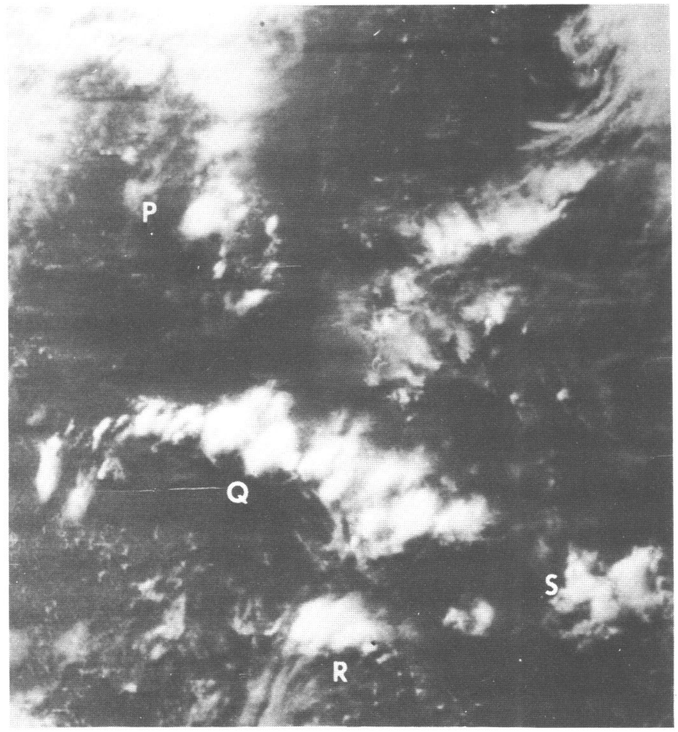


FIGURE 4.—ATS-III, June 21, 1968, 2126 GMT (1726 EDT).

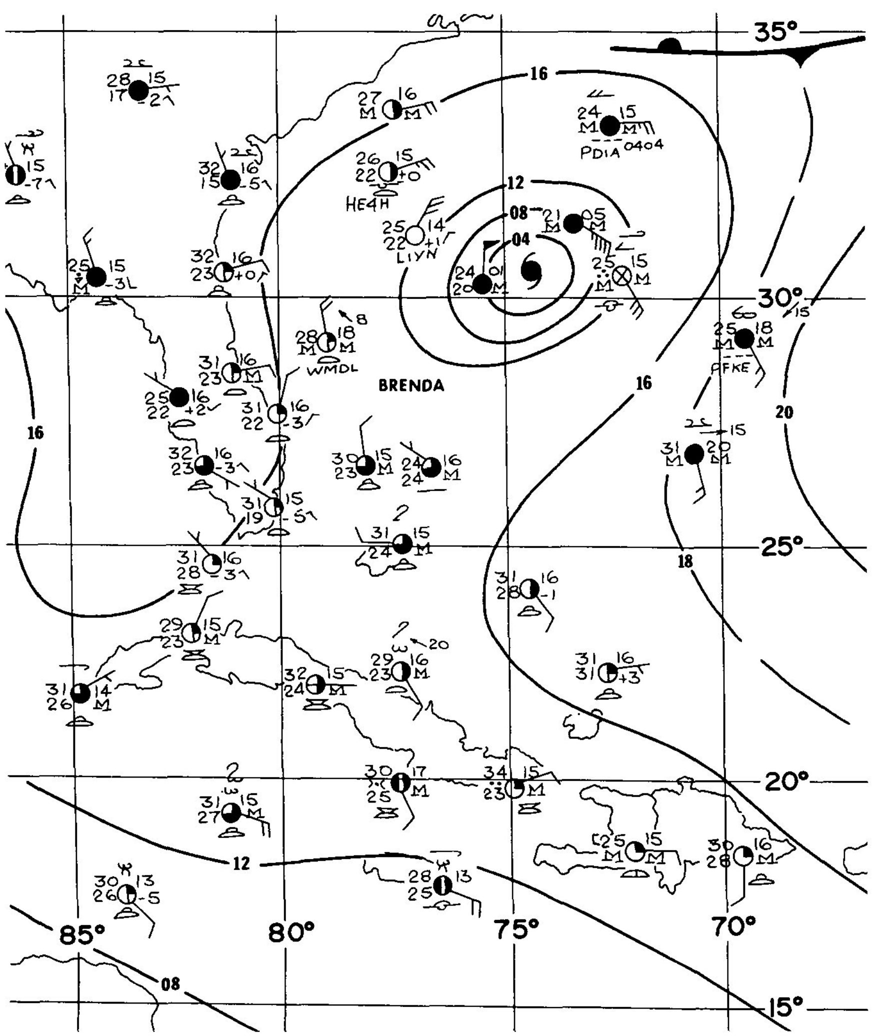


FIGURE 5.—1800 GMT surface tropical analysis, June 21, 1968.